PB86-117868

Summary of Available Information Related to the Occurrence of Vinyl Chloride and Ground Water as a Transformation Product of Other Volatile Organic Chemicals

Science Applications International Corp.
McLean, VA

Prepared for

Environmental Protection Agency, Washington, DC

9 Oct 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-117868

SUMMARY OF AVAILABLE INFORMATION RELATED TO THE OCCURRENCE OF VINYL CHLORIDE AND GROUND WATER AS A TRANSFORMATION PRODUCT OF OTHER VOLATILE ORGANIC CHEMICALS

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EPA Contract No. 68-01-7166, Work Assignment 5
SAIC Project No. 2-813-07-545-05

EPA Project Officer
Mr. William Coniglio

October 9, 1985

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

2.	3. RECIPIENT'S ACCESSION NO. PB86 117868/AS
SUBTITLE Summary of Available Information Related to the Occurrence of Vinyl Chloride in Ground Water as Transformation Product of other Volatile Organic Chemicals	5. REPORT DATE 10/85 6. PERFORMING ORGANIZATION CODE
AUTHOR(S) U.S. Environmental Protection Agency	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Drinking Water (WH-550) 401 M St., S.W., Washington, D.C. 20460	13. TYPE OF REPORT AND PERIOD COVERED Scientific review 14. SPONSORING AGENCY CODE EPA/CSD

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The Office of Drinking Water (ODW), U.S. Environmental Protection Agency has prepared a document which discusses the available scientific information related to the occurrence of vinyl chloride and other chlorinated organics in ground water, as a transformation product of other volatile organic chemicals. This document presents a review of the available scientific data on this topic.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Vinyl chloride Transformation product Ground Water Volatile Organic Chemicals		

18. DISTRIBUTION STATEMENT OPEN	19. SECURITY CLASS (This Report) Non-sensitive 20. SECURITY CLASS (This page) Non-sensitive	21. NO. OF PAGES 21 22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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1. INTRODUCTION

In 1982 and 1983, the EPA Office of Drinking Water prepared a series of assessments on the occurrence of several volatile organic chemicals (VOCs) in public drinking water supplies. In those assessments, the occurrence of each VOC in drinking water was considered to be due primarily to environmental releases associated with the industrial and commercial uses of that substance and/or the disposal of wastes containing that substance. Subsequent to the completion of those assessments, information became available to suggest that the presence of certain VOCs in ground water may be due, at least in part, to biologically mediated transformations of other VOCs.

Most notable among these potential transformation processes is the degradation of trichloroethylene and tetrachloroethylene (through one or more dichloroethylene isomer intermediate) to vinyl chloride. The formation of vinyl chloride from trichloroethylene and tetrachloroethylene in ground water is a focal point of concern because vinyl chloride is a potent carcinogen (having a drinking water risk level approximately two orders of magnitude greater than that of trichloroethyene, and because trichloroethylene and tetrachloroethylene are the two most frequently found VOC contaminants in ground water drinking water supplies.

The purpose of this document is to summarize the available information relevant to assessing the extent to which vinyl chloride may be occurring in ground water based drinking water supplies as a transformation product. Section 2 summarizes the available information on observed chloride occurrence in ground water drinking water supplies. Section 3 examines the co-occurrence of vinyl chloride with other VOCs. Section 4 reviews information relevant to the transformation of certain VOCs to vinyl chloride in ground-water environments.

2. OCCURRENCE OF VINYL CHLORIDE IN GROUND WATER DRINKING WATER SUPPLIES

2.1 OFFICE OF DRINKING WATER OCCURRENCE ESTIMATES

The information available through mid-1983 on the occurrence of vinyl chloride in ground water drinking water supplies was presented by EPA's Office of Drinking Water in a document prepared in support of the June 12, 1984, Federal Register Notice (USEPA 1984) publication of the proposed rule on VOCs under the Safe Drinking Water Act (Letkiewicz et al. 1983). The relevant information from that document is summarized below.

Vinyl chloride was included as an analyte in three Federal drinking water surveys. In Phase II of the National Organic Monitoring Survey conducted May-July 1976, 18 ground water supplies were sampled for vinyl chloride; none was detected (minimum quantifiable limit - 0.1 ug/l). In the National Screening Program conducted between 1971 and 1981, vinyl chloride was observed in 2 of 12 ground water supplies sampled at concentrations of 9.4 ug/l and 66 ug/l (quantification limit = 0.2 ug/l). In the Ground Water Supply Survey conducted in 1981, vinyl chloride was found in 7 of 929 public water supplies examined at concentrations ranging from 1.1-8.4 ug/l (minimum quantitation limit = 1.0 ug/l).

Based on those limited data, it was estimated that vinyl chloride occurs at levels above 1.0 ug/l in 0.06% of the nation's ground water public drinking water supplies. To place that value in perspective, the most frequently observed VOCs in ground water public water supplies are trichloroethylene (3.4%), tetrachloroethylene (3.2%), and 1,1,1-trichloroethane (2.9%). It should be noted that the frequencies of occurrence of those substances are for levels of 0.5 ug/l or more. Consequently, a more directly comparable estimate of national vinyl chloride occurrence at or above 0.5 ug/l would probably be higher than 0.06%, but the value cannot be estimated from existing data.

Limited state data available from New Jersey and New York were also presented in the Office of Drinking Water report. In New Jersey, vinyl chloride was reported to be present in 6 of 21 ground water drinking water samples taken from Fair Lawn and Mahwah, New Jersey. The concentrations ranged from 1.1-51 ug/l. No vinyl chloride was observed in 425 samples taken at other locations in New Jersey. Vinyl chloride was not detected in 125 finished water ground water samples taken in New York.

The Federal survey data and state data presented in the 1983 occurrence document did not provide any details relevant to assessing the sources of contamination observed. As noted previously, it was assumed then that the vinyl chloride observed in drinking water was related to industrial uses and/or waste management practices.

2.2 ADDITIONAL OCCURRENCE INFORMATION

Mello (1984) summarized the results of a 1982 ground water survey conducted in three states in Region VII (Kansas, Missouri, and Nebraska) to measure VOC levels. Vinyl chloride was observed in only 1 of 208 public water supplies studied, at a concentration of 1.2 ug/l (quantitation limit = 1.0 ug/l).

Brass (1985) provided data from the Office of Drinking Water's Packed Tower Aeration Project showing vinyl chloride to be present at seven locations at concentrations ranging from 1-640 ug/l. No other details were provided.

Vincent (1984) examined the occurrence of VOCs, including vinyl chloride, in the ground water drinking water supplies in Broward, Dade, and Palm Beach counties of south Florida. Vinyl chloride was observed in finished water in one supply in Palm Beach county (2 ug/l) and one in Dade county (2 ug/l). The most frequently observed VOC (other than trihalomethanes) was *cis-/trans*-1,2-dichloroethylene.

Vincent (1984) sought to identify the sources of the VOCs observed in this study, and could find no reasonable industrial, commercial, or waste disposal source to explain the presence of the observed vinyl chloride. Vincent (1984) referenced research at Florida International University (discussed in more detail in Section 4 of this document) to suggest that the observed vinyl chloride -- as well as *cis-/trans*-1,2-dichloroethylene, 1,1-dichloroethylene, and 1,2-dichloroethane -- were biodegradation products of trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane, all solvents with considerable use and release in the study areas.

Vincent (1984) also noted other locations (in Long Island, New York; eastern Pennsylvania; and California) where trichloroethylene contamination of ground water occurred and vinyl chloride was subsequently detected. No details were provided, however, except that in all cases a contributing factor

appeared to be bacterial contamination from septic tank sludges or other biological sludges.

3. INFORMATION ON THE CO-OCCURRENCE OF VINYL CHLORIDE WITH OTHER VOCs

When the 1983 VOC occurrence estimates were prepared by the Office of Drinking Water, the focus of the analyses was on the frequency of occurrence of each individual VOC independent of any other contaminant. Although some limited analyses were conducted on the frequency of single, multiple, and cumulative occurrences of VOCs in the Federal surveys (see USEPA 1984), no consideration was given at that time to the co-occurrence of specific pairs or larger groups of VOCs.

Subsequently, Brass (1985) reviewed co-occurrence information for vinyl chloride based on data from the Ground Water Supply Survey, the Region VII Survey, and the Packed Tower Aeration Project. In all of the 15 ground water supplies containing vinyl chloride observed in those surveys, other VOCs were also present. The most frequently co-occurring VOCs were:

cis-/trans-1,2-dichloroethylene	15 co-occurrences
trichloroethylene	12 co-occurrences
1,1-dichloroethane	10 co-occurrences
1,1-dichloroethylene	9 co-occurrences
tetrachloroethylene	7 co-occurrences
1,1,1-trichloroethane	6 co-occurrences

In the two vinyl chloride occurrences reported for the National Screening Program, there was co-occurrence with *cis*- and *trans*-1,2-dichloroethylene, trichloroethylene, and 1,1-dichloroethane in one supply, and no co-occurrence with any of the above VOCs in the other.

Table 1 from Brass (1985) shows the specific co-occurrence values for the chlorinated aliphatic VOCs examined in the Ground Water Supply Survey. A statistical test of the Ground Water Supply Survey co-occurrence data was conducted by SAIC to identify those pairs which co-occur with a greater frequency than would be expected based upon the individual frequency of occurrence of each substance and assuming that co-occurrence is a random event.

The probability density function for the number of co-occurrences of any two VOCs can be expressed as a hypergeometric distribution with parameters N (the total number of smaples in the survey) and a and b (the number of indivi-

Table 1. Co-Occurrence of Chlorinated Aliphatic VOCs in the Ground Water Supply Survey (December 1980-December 1981)

	Vinyl chloride	1,2-Dichloroethane	1,2-Dichloropropane	1,1-Dichloroethylene	Carbon tetrachloride	1,1-Dichloroethane	*cis/trans*-1,2-Dichloroethylene	1,1,1-Trichloroethane	Tetrachloroethylene	Trichloroethylene
Vinyl chloride	7	1	0	3	1	5	7	3	1	6
1,2-Dichloroethane		10	1	3	5	1	2	2	3	3
1,2-Dichloropropane			13	1	0	2	3	3	1	3
1,1-Dichloroethylene				24	3	17	11	16	7	17
Carbon tetrachloride					30	2	4	4	7	6
1,1-Dichloroethane						41	21	28	16	26
cis/trans-1,2-Dichloroethylene							54	23	23	45
1,1,1-Trichloroethane								78	35	45
Tetrachloroethylene									79	39
Trichloroethylene										91

Source: Brass 1985

dual occurrences of each VOC in the pair). To test whether the observed number of co-occurrences is a random phenomena (according to the probabilities specified by the hypergeometric distribution) versus the hypothesis that the observed co-occurrence is something other than random, a hypothesis test at a specified significance level (usually 0.05 or 0.01) can be conducted, based on this distribution. If the number of co-occurrences equals or exceeds a critical value determined by the parameters of the hypergeometric distribution and the significance level, the hypothesis of randomness is rejected in favor of non-randomness. If the number of co-occurrences does not exceed this critical value, the hypothesis of randomness cannot be rejected.

Table 2 presents the results of the analysis. Table 2 shows for each pair of VOCs the individual number of occurrences and the number of co-occurrences. Two hypergeometric probabilities are shown. The first is the probability of observing the specific number of co-occurrences that were in fact observed; the second is the cumulative probability of observing the number of co-occurrences actually seen and all possible higher numbers of co-occurrences. The last two columns show the minimum number of co-occurrences needed for each pair to conclude that co-occurrence was a non-random event at the 0.05 and 0.01 level, respectively.

As indicated in Table 2, about half of the VOC pairs show frequencies of co-occurrence in the Ground Water Supply Study that exceed the amount that would be expected by chance at the 0.05 and 0.01 level. Only 1,2-dichloropropane did not co-occur with any other VOC at a significant frequency, while carbon tetrachloride and 1,2-dichloroethane co-occurred with only one other VOC each at a significant frequency. The remaining seven VOCs each co-occurred with between 4 and 7 other VOCs at significant frequencies.

Vinyl chloride shows significant co-occurrence with *cis/trans*-1,2-dichloroethylene, 1,1-dichloroethylene, trichloroethylene, and 1,1-dichloroethane. However, the reasons for its co-occurrence with those substances in the Ground Water Supply Survey cannot be determined due to lack of detailed information concerning the sites and conditions where it was observed.

VOCs may occur together because of geographic proximity of individual sources, common use patterns, co-occurrence in certain products or wastes as contaminants or by-products, disposal at a common waste site responsible for the observed ground water contamination, and/or chemical or biological trans-

Table 2. Hypergeometric Probabilities of Observed Co-Occurrence of Chlorinated Aliphatic VOCs in the Ground Water Supply Survey

First VOC (occurrence)	Second VOC (occurrence)	Observed co-occurrence	Hypergeometric probability of observed co-occurrence	Cumulative hypergeometric probability of co-occurrence greater than or equal to observed co-occurrence	Minimum number of co-occurrences to exceed critical value	
					0.05 level	0.01 level
Vinyl chloride (7)	1,2-Dichloroethane (10)	1	0.071099	0.07319	2	2
Vinyl chloride (7)	1,2-Dichloropropane (13)	0	0.905711	1.00000	2	2
1,2-Dichloroethane (10)	1,2-Dichloropropane (13)	1	0.124404	0.13205	2	2
Vinyl chloride (7)	1,1-Dichloroethylene (24)	3	0.000485	0.00050	2*	3*
1,2-Dichloroethane (10)	1,1-Dichloroethylene (24)	3	0.001552	0.00162	2*	3*
1,2-Dichloropropane (13)	1,1-Dichloroethylene (24)	1	0.248059	0.29001	2	3
Vinyl chloride (7)	Carbon tetrachloride (30)	1	0.186744	0.20589	2	3
1,2-Dichloroethane (10)	Carbon tetrachloride (30)	5	0.000005	0.00001	2*	3*
1,2-Dichloropropane (13)	Carbon tetrachloride (30)	0	0.650794	1.00000	3	3
1,1-Dichloroethylene (24)	Carbon tetrachloride (30)	3	0.032913	0.03891	3*	4
Vinyl chloride (7)	1,1-Dichloroethane (41)	5	0.000003	0.00000	2*	3*
1,2-Dichloroethane (10)	1,1-Dichloroethane (41)	1	0.296339	0.36468	3	3
1,2-Dichloropropane (13)	1,1-Dichloroethane (41)	2	0.092236	0.10901	3	4
1,1-Dichloroethylene (24)	1,1-Dichloroethane (41)	17	0.000000	0.00000	4*	5*
Carbon tetrachloride (30)	1,1-Dichloroethane (41)	2	0.243872	0.38586	4	5
Vinyl chloride (7)	*cis/trans*-1,2-Dichloroethylene (54)	7	0.000000	0.00000	3*	3*
1,2-Dichloroethane (10)	*cis/trans*-1,2-Dichloroethylene (54)	2	0.093964	0.11063	3	4
1,2-Dichloropropane (13)	*cis/trans*-1,2-Dichloroethylene (54)	3	0.030139	0.03507	3*	4
1,1-Dichloroethylene (24)	*cis/trans*-1,2-Dichloroethylene (54)	11	0.000000	0.00000	4*	6*
Carbon tetarchloride (30)	*cis/trans*-1,2-Dichloroethylene (54)	4	0.064931	0.09065	5	6
1,1-Dichloroethane (41)	*cis/trans*-1,2-Dichloroethylene (54)	21	0.000000	0.00000	6*	7*
Vinyl chloride (7)	1,1,1-Trichloroethane (78)	3	0.014251	0.01558	3*	4
1,2-Dichloroethane (10)	1,1,1-Trichloroethane (78)	2	0.157708	0.20212	3	4
1,2-Dichloropropane (13)	1,1,1-Trichloroethane (78)	3	0.069893	0.08823	4	5
1,1-Dichloroethylene (24)	1,1,1-Trichloroethane (78)	16	0.000000	0.00000	5*	7*
Carbon tetrachloride (30)	1,1,1-Trichloroethane (78)	4	0.140602	0.23958	6	7
1,1-Dichloroethane (41)	1,1,1-Trichloroethane (78)	28	0.000000	0.00000	7*	9*
cis/trans-1,2-Dichloroethylene (54)	1,1,1-Trichloroethane (78)	23	0.000000	0.00000	9*	11*
Vinyl chloride (7)	Tetrachloroethylene (79)	1	0.350985	0.46432	3	4
1,2-Dichloroethane (10)	Tetrachloroethylene (79)	3	0.039041	0.04590	3*	4
1,2-Dichloropropane (13)	Tetrachloroethylene (79)	1	0.382954	0.68752	4	5
1,1-Dichloroethylene (24)	Tetrachloroethylene (79)	7	0.002147	0.00261	5*	7*
Carbon tetrachloride (30)	Tetrachloroethylene (79)	7	0.007668	0.01007	6*	8
1,1-Dichloroethane (41)	Tetrachloroethylene (79)	16	0.000000	0.00000	8*	9*
cis/trans-1,2-Dichloroethylene (54)	Tetrachloroethylene (79)	23	0.000000	0.00000	9*	11*
1,1,1-Trichloroethane (78)	Tetrachloroethylene (79)	35	0.000000	0.00000	12*	14*
Vinyl chloride (7)	Trichloroethylene (91)	6	0.000005	0.00000	3*	4*
1,2-Dichloroethane (10)	Trichloroethylene (91)	3	0.054275	0.06570	4	5
1,2-Dichloropropane (13)	Trichloroethylene (91)	3	0.095608	0.12650	4	5
1,1-Dichloroethylene (24)	Trichloroethylene (91)	17	0.000000	0.00000	6*	7*
Carbon tetrachloride (30)	Trichloroethylene (91)	6	0.042986	0.06432	7	8
1,1-Dichloroethane (41)	Trichloroethylene (91)	26	0.000000	0.00000	8*	10*
cis/trans-1,2-Dichloroethylene (54)	Trichloroethylene (91)	45	0.000000	0.00000	10*	12*
1,1,1-Trichloroethane (78)	Trichloroethylene (91)	45	0.000000	0.00000	13*	15*
Tetrachloroethylene (79)	Trichloroethylene (91)	39	0.000000	0.00000	13*	15*

*Observed co-occurrence greater than minimum number of occurrences needed to exceed critical value.

formation from one to the other. The significant co-occurrences of vinyl chloride and other VOCs noted here does not provide any insight as to the processes involved. Furthermore, absence of observed co-occurrence does not necessarily negate a relationship involving transformation since the starting compound may be consumed during the process and no longer be measureable.

4. TRANSFORMATION OF TRICHLOROETHYLENE AND TETRACHLOROETHYLENE TO VINYL CHLORIDE IN GROUND WATER ENVIRONMENTS

As noted in the preceeding section, there are a number of possible explanations for the observed co-occurrence of vinyl chloride with other VOCs in ground water. This section examines the available information related to one of those explanations, namely, the transformation of other substances to vinyl chloride. The available information suggests that tetrachloroethylene and trichloroethylene are the likely precursors of vinyl chloride, which would be formed via sequential dechlorination with *cis*-1,2-dichloroethylene, *trans*-1,2-dichloroethylene, and/or 1,1-dichloroethylene as intermediates (Parsons et al. 1985). While hypothetical pathways from other frequently observed VOCs, such as 1,1,1-trichloroethane, can be suggested, no evidence showing their existence was found. Therefore, only transformations involving trichloroethylene and tetrachloroethylene are considered here.

The transformation of substances present in ground water may occur through chemical or biological processes. The major types of chemical reactions that can transform organic contaminants in water are oxidation and hydrolysis. Callahan et al. (1979), primarily citing the work of Dilling et al. (1975) indicate that neither oxidation nor hydrolysis are significant water-related fate processes for trichloroethylene or tetrachloroethylene. The half-lives for combined oxidation and hydrolysis at 25°C were 10.7 months and 8.8 months for trichloroethylene and tetrachloroethylene, respectively. Callahan et al. (1975) did not indicate what the intermediate or final products of oxidation or hydrolysis would be. However, oxidation and hydrolysis reactions with unsaturated compounds such as trichloroethylene and tetrachloroethylene would be expected to involve addition across the carbon-carbon double bond and not the dechlorination processes necessary to produce vinyl chloride.

The available information on the biological degradation of tetrachloroethylene and trichloroethylene indicates that there are some conditions under which such transformations will occur and other conditions under which they will not.

Bouwer et al. (1981) studied the aerobic and anaerobic biodegration of 1- and 2-carbon halogenated compounds, including trichloroethylene and tetra-

chloroethylene, in aqueous media. In the aerobic studies, the substances were incubated in 160 ml serum bottles filled with an aqueous mineral medium to which a bacterial innoculum (primary sewage effluent) was added. In the anaerobic studies, the compounds were incubated in 160 ml bottles containing an aqueous anaerobic medium seeded with 1 ml of a methanogenic mixed culture. Three series of bottles were prepared for each study having low, medium, or high concentrations (approximately 10, 30, and 100 ug/l) of each substance.

Under the aerobic conditions, there was no observed degradation of either trichloroethylene or tetrachloroethylene after 25 weeks of incubation. In the anaerobic study, small decreases in trichloroethylene and tetrachloroethylene concentrations relative to the controls were observed after week 12 of the 16-week incubation period. The authors noted that the changes observed suggested possible slow decomposition, but that the results were not conclusive. The authors did not address degradation products or mechanisms of degradation.

In a subsequent study, Bouwer and McCarty (1983) conducted additional anaerobic degradation experiments using conditions similar to those noted above, except that 60 ml serum bottles were used, the methanogenic mixed culture was added at 10 ml/l (versus approximately 6 ml/l in the previous study), and initial concentrations of trichloroethylene and tetrachloroethylene were 200 ug/l. After approximately 8 weeks, a 40% reduction in trichloroethylene levels was observed. For tetrachloroethylene, the concentration declined to below the detection limit of 0.1 ug/l after 8 weeks. The authors also observed that after 8 weeks, the seeded cultures incubated with tetrachloroethylene had 91 ug/l of trichloroethylene present, suggesting the latter to be a product of tetrachloroethylene biodegradation. Evidence of tetrachloroethylene conversion to trichloroethylene was also observed by Bouwer and McCarty (1983) in continuous-flow studies through an aerobic column containing methanogenic bacteria. (The methanogenic columns were acclimated to a sodium acetate substrate for 15 months prior to the addition of tetrachloroethylene to the influent.) After 10 weeks of acclimation to tetrachloroethylene, an 86 ± 7% steady state removal rate was observed (18 ± 3 ug/l in the influent vs. 2.6 ± 1.3 ug/l in the effluent); also, 1.2 ± 0.6 ug/l of trichloroethylene was observed in the column effluent whereas none had been added to the influent,

again suggesting that trichloroethylene is a biodegradation product of tetrachloroethylene. Further degradation products were not analyzed for.

Walker (1984) studied the fate of trichloroethylene in two different soils (Chalmus Silty Clay Loam and Russel Silt Loam) under conditions of a simulated spill or discharge. Trichloroethylene (5 or 10 ml) was applied to the surface of each column, with 50 or 100 ml/day of water added to provide continuous elution for 132 days. No significant degradation (abiotic or biological) was observed. The columns were tested to determine if nutrient enrichment, by adding ammonia nitrogen, would enhance biodegradation processes. Although effluent chloride levels of the enriched columns increased, it was not significant and the corresponding trichloroethylene degradation could not be measured. Neither *cis*- nor *trans*-1,2-dichloroethylene was observed in the column effluent (minimum detection limit stated to be 2 mg/l; it is likely that this is a typographical error and should be 2 ug/l).

Wilson et al. (1983) examined the biological degradation of trichloroethylene and tetrachloroethylene in subsurface materials taken above and below the water table at Fort Polk, Louisiana, and Pickett, Oklahoma, described as "fairly typical of shallow, water-table aquifers in the south-central region of the United States." The depths from which the materials were taken were 2.1 m and 3.6 m for above and below the water table, respecitvely, at Fort Polk; and 3.6 m and 4.8 m for above and below the water table, respectively, at Pickett. The samples were noted to be aerobic when collected. Trichloroethylene or tetrachloroethylene were added to microcosms prepared from the subsurface material at concenrations of 600-800 ug/l. The microcosms were incubated up to 9 weeks for the Fort Polk samples and 27 weeks for the Pickett samples. Contaminant levels were measured at intervals during the incubation period.

There was detectable degradation of both contaminants over the study period in some of the subsurface materials. However, the rates of degradation were comparable to abiotic degradation rates noted by the authors as reported by Dilling et al. (1975) (1.6 and 2.0% wk^{-1} for trichloroethylene and tetrachloroethylene, respectively). The authors, therefore, concluded that the observed degradation may not have been due to biological processes. The authors did not address the potential products or mechanisms of degradation.

Wilson et al. (1984) reported similar loss rates of 1.0 and 1.5% wk^{-1} for trichloroethylene and tetrachloroethylene in similar subsurface microcosm studies. As in the previous study, the authors could not preclude nonbiological processes to account for the loss rate. In this study, the pore water of the microcosm was examined for the potential products of biologically mediated reductive dehalogenation, including vinyl chloride, 1,1-dichloroethylene, and 1,2-dichloroethylene. None were reported to be found at concentrations of up to 1% of the potential parent compound.

Wilson and Wilson (1985) demonstrated that trichloroethylene could be degraded aerobically to carbon dioxide in sandy soil that had previously been exposed to natural gas to enrich it for methanotrophic bacteria and other organisms that oxidize the other small alkanes present in natural gas. Using radiolabelled [^{14}C]-trichloroethylene, the author determined that the transformation to carbon dioxide was essentially complete; they did not identify or speculate on the nature of any intermediate products.

Parsons et al. (1985) conducted static microcosm studies to measure the extent to which tetrachloroethylene could be biologically degraded by microorganisms present in the muck bed of the Florida Everglades, which serve as the primary recharge basin for the Biscayne aquifer in southeastern Florida. This study was specifically performed to determine whether such processes could account for the presence of vinyl chloride and *cis*- and *trans*-1,2-dichloroethylene found in the ground water in southern Florida, for which no industrial or other sources could be identified (see earlier discussion of Vincent 1984).

In one set of studies, 10 ml of muck collected from a pristine site was placed in each of seven 60-ml septum bottles. Surface water collected a the same time as the muck was added to fill each bottle. A 10-ul methanol solution containing 100 ug of tetrachloroethylene was added to each bottle (the 100 ug of tetrachloroethylene was also found to have approximately 1.6 ug of trichloroethylene present as a contaminant). Controls of muck and surface water without tetrachloroethylene, sterile (autoclaved) muck and surface water with tetrachloroethylene, and sterile distilled water with tetrachloroethylene were also prepared.

Of the 100-ug tetrachloroethylene initially added to each bottle, an average of 87 and 83 ug were measured in the water of the test and autoclaved

control bottles, respectively, immediately after each was capped and shaken; the remaining amount was believed to have been absorbed to the muck solids. After 21 days incubation, the amount of tetrachloroethylene in the test bottles had declined to 28 ug. No loss of tetrachloroethylene was observed in the autoclaved control or distilled water control; the unspiked muck control yielded no chlorinated compounds.

Trichloroethylene was observed to increase from 1.1 ug at day 0 to 4.7 ug after 21 days; no change was observed in the autoclaved muck. In addition, several compounds were observed in the test muck after 21 days that were not present at day 0 or observed in the autoclaved controls (detection limit, 0.03 ug). These were *cis*-1,2-dichloroethylene (3.8 ug), *trans*-1,2-dichloroethylene (0.11 ug), vinyl chloride (1.7 ug), and 1,1-dichloroethylene and/or dichloromethane (0.15 ug) (the latter two substances could not be distinguished with the method used). Parsons et al. (1985) speculated that the test conditions were anaerobic or nearly anaerobic.

Parsons et al. (1985) performed similar microcosm tests on five additional samples of muck and one of marl collected from different parts of the Everglades. In these studies, 250 ug of tetrachloroethylene was added to the 60 ml test bottles. In these assays, the levels of tetrachloroethylene transformation was reported to be very low (no details provided), with only occasional trace levels of chlorinated by-products formed.

Mackay et al. (1985) noted in their general discussion of biological transformation of organic contaminants in ground water that there are many factors that can affect the rate of biotransformation including water temperature and pH, the types of microorganisms present and their population, oxygen levels, the substrate concentration, and the availability of electron acceptors. Also, in some cases, native organisms may not be able to transform a specific compound, or do so only after a period of acclimation.

The results of the several studies summarized above should be considered in light of such factors. Some ground water conditions, such as those studied by Parsons et al. (1985) may result in extensive biotransformation of tetrachloroethylene and trichloroethylene to products such as vinyl chloride, while other conditions will yield little or no degradation. Except for noting that the processes appear to be anaerobic, the information available is not sufficient to fully characterize the necessary conditions for such transformations

to occur, nor to speculate on the extent to which such transformations are occurring in U.S. ground water contaminated with trichloroethylene or tetrachloroethylene. However, that such processes can occur in some situations seems clearly demonstrated by the available information.

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